Carbon^Re

Levers of Change

Exploring regulatory and commercial factors driving decarbonization in the cement industry

Who we are

We are a company pushing the boundaries of artificial intelligence to accelerate the decarbonization of cement and other foundational materials.

Our first product is Delta Zero, a software platform that embodies cement process expertise and the latest state-of-the-art capabilities in AI. Delta Zero supports operators in managing the complexities of cement production and provides them with clear, actionable recommendations for process set-points, resulting in significantly reduced energy consumption and CO2 emissions.

Delta Zero provides tailored recommendations to plant operators that can reduce energy consumption by 10% and fuel-derived carbon emissions by up to 20%. Our software is compatible with both Expert System operations and manual operator control and achieves gains that cannot be obtained through Expert Systems or operator training.

No capital investment, no new equipment, and no plant shutdowns are needed. Delta Zero enables ongoing cement plant optimization to account for changing process inputs and outside pressures such as volatile fuel market costs and emissions regulations. Substantial savings in energy are achieved by empowering operators to run each plant at its highest possible efficiency levels, resulting in several percentage points of fuel use savings. This equates to very substantial cost savings.

Delta Zero also enables critical secondary benefits, such as helping maintain equipment within operating parameters (e.g. kiln torque) and keeping NOx emissions within control limits. We are further exploring future benefits our technology promises, such as predicting and avoiding kiln blockages.

Find out more at carbonre.com/delta-zero/

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Executive summary

The cement industry produces one of the most ubiquitous and necessary materials for the modern world but it comes with a significant carbon footprint. The scale and importance of decarbonizing the industry that is responsible for 8% of global greenhouse gas emissions has gained recognition in recent years, yet there is much to be done to convert pledges into action.

With demand for cement set to increase and strict climate targets required to be met in the coming decades, we set out to provide a reference of the regulatory and commercial factors driving decarbonization in the cement industry so that relevant stakeholders can examine the landscape and determine which levers of change could be further exploited in their context.

This paper dives into how global standards and regulations are changing the game, setting new, greener rules for cement production. Whether it's global bodies pushing for new eco-friendly standards or the introduction of carbon taxes and trading schemes, the standards and regulatory landscape is exerting enormous pressure on the cement industry.

We explore the increasing customer demand for low-carbon cement products, both from construction companies and regulatory bodies, and highlight global initiatives like the First Movers Coalition and Concrete Zero initiative and new bodies such as the Alliance for Low Carbon Cement & Concrete. These are the crusaders in the quest for low-emission cement and concrete – whether that's achieved through improving the process or the formulation – setting ambitious targets that are anything but set in stone. We also look at some of those leading by example with projects that have already embraced the low-carbon cement mantra, showing it's not just about what's being built, but what's building it and the standards to which it must adhere.

Looking to the cement production process itself, we explore both established and emerging decarbonization technologies. The current methods involve the use of substitute cementitious materials to replace clinker, alternative fuels to substitute fossil-derived fuels, and increasing energy efficiency through hardware and software upgrades. Newer technologies such as carbon capture and storage, green hydrogen fuel and

electrification through renewable electricity and electrolysis, as well as chemical or biological additives to cement mixes, are all in development to become commercially scalable solutions.

And we haven't forgotten the real-world action by producers themselves, who are seeing increasing commercial advantage to decarbonizing their processes and products. As these technologies can work to reduce the costs of production as well as improve the differentiation and reputation of cement producers by offering low-carbon solutions, there is an opportunity to innovate and become a major contributor to a market of green cement, for which there is increasing customer demand and encouragement by public procurement policies.

Finally, cement companies will need to look to various sources of capital and financing to cover the cost of plant upgrades and implementing decarbonization technologies. Cement production is a huge, globally distributed business that requires huge investment. Fortunately, there are multiple options available, including increasingly popular Sustainability-linked Loans (SLLs) and Green bonds. National governments must also provide incentives in the form of tax breaks, grants, and low-interest loans to further enhance the widespread adoption of green technologies.

There is conflicting information on the cement industry's progress in reducing their emissions with some sources indicating a reduction in emissions by up to a fifth since 1990[1] and others reporting a doubling of emissions in the same time frame.[2] However, there is no doubt that the industry needs to reduce its emissions to be on track for Net Zero by 2050, with the IEA stating a reduction in carbon emissions by 4% each year through to 2030 is required.[3]

Within this context, "Levers of Change'' outlines how everyone involved in the highly complex cement ecosystem can be even more ambitious about how to decarbonize the industry.

How can we all lay the right foundations (pun intended) for a cement sector that's as robust in sustainability as it is in structure?

1 *Global cement and concrete industry announces roadmap to achieve groundbreaking 'net zero' CO2 emissions by 2050.* GCCA (October 2021). https://gccassociation.org/news/global-cement-and-concrete-industry-announces-roadmap-to-achieve-groundbreaking-net-zero-co2-emissions-by-2050

2 Andrew, R.M., 2019. Global CO2 emissions from cement production, 1928–2018. Earth System Science Data 11, 1675–1710 https://zenodo.org/records/6553090#.YrlzkXbMJPb

3 *Cement.* IEA (July 2023). https://www.iea.org/energy-system/industry/cement#tracking

Introduction

Cement is ubiquitous. Nearly every building and infrastructure that we live, work, and travel on is supported by this material. Yet, underlying this unassumingly grey foundational material is an industry bound by its enormous global carbon footprint: one urgently pursuing a green transformation.

There is conflicting information on the cement industry's progress in reducing their emissions with some sources indicating a reduction in emissions by up to a fifth since 1990[4] and others reporting a doubling of emissions in the same timeframe.[5] Nonetheless, research shows that not hitting net zero (but making good progress by 2030) delivers a significantly better result than hitting net zero through a big improvement between 2040 and 2050.[6] This is due to the time value of carbon which means that emissions made between now and 2030 will have longer in the atmosphere to drive climate change than gases emitted in the future.

Regardless of the progress made to date, to be on track for Net Zero by 2050, the cement industry needs to reduce carbon emissions by 4% each year through to 2030.[7]

The movement towards decarbonization, or the reduction of greenhouse gas emissions, is currently being driven by a number of factors that we explore in this paper. These levers of change include:

- Existing standards
- New regulations
- Customer demand
- Technologies both existing and new
- Commercial advantages
- Capital and financing

Our research outlines the regulatory, technological, and commercial landscape in which the complex cement ecosystem must navigate to decarbonize the industry. We also explore the ways in which cement producers and stakeholders can lay the foundation for sustainable practices that are as robust as cement in its structure and prevalence.

4 *GNR 2.0 – GCCA in Numbers.* GCCA (2021). https://gccassociation.org/sustainability-innovation/gnr-gcca-in-numbers/

5 Andrew, Robbie. Global CO2 emissions from cement production. Zenodo (May 2022). https://doi.org/10.5281/zenodo.6553090

6 Sun, T., Ocko, I.B., Sturcken, E. et al. Path to net zero is critical to climate outcome. Sci Rep 11, 22173 (November 2021). https://doi.org/10.1038/s41598-021-01639-y

7 Tracking Cement. International Energy Agency. https://www.iea.org/energy-system/industry/cement

Standards

Cement and concrete standards are instrumental in the evaluation and testing of concrete, cement, and aggregates.

The specific standards differ according to the type and required use of the cement:

- **Type I:** General-purpose cement suitable for use when special properties are not required.
- **Type II:** For general use, more especially when moderate sulphate resistance or moderate heat of hydration is desired.
- **Type III:** For use when high early strength is desired.
- **Type IV:** For use when a low heat of hydration is desired.[8]

Primarily, cement standards ensure safety, quality, interoperability, and eco-friendliness of all concrete structures.

Safety and quality

In September 2023, over 100 schools and public buildings were closed across the UK due to safety concerns over crumbling reinforced autoclaved aerated concrete (RAAC). As this event highlights, standards set on the quality of cement directly relate to human safety. Buildings and infrastructure must withstand various environmental factors, including seismic activity, extreme weather conditions (which have become more frequent and intense in recent years), and the test of time. Standards establish the criteria for acceptable strength and durability of cement, ensuring that structures remain safe throughout their lifespans.

Interoperability

Cement products from various manufacturers must all be seamlessly interoperable, or capable of being used together. This is particularly true for large-scale construction projects where materials from multiple sources may be required. Furthermore, uniform standards ensure that all players in the industry are held to the same criteria, fostering a level playing field and promoting healthy competition in decarbonization efforts.

Environment and innovation

When implemented effectively, standards and regulations can also serve as powerful tools to incentivize and guide businesses towards environmentally friendly practices. For the cement industry, this means adopting innovative production techniques to meet new product specifications, utilizing alternative materials that are more sustainable than 'traditional' materials, and embracing carbon capture and storage solutions.

Limitations of standards

There is no single international organization defining global standards for cement. The American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO) are the two primary institutes responsible for setting cement standards, and most cement producers adhere to either ASTM's or ISO's criteria for measuring properties and physical characteristics of cement production.

Cembureau, the European Cement Association based in Belgium, regularly publishes their *Cement Standards of the World* report which summarizes cement standards and trends across 84 countries. In their latest edition published in

8 https://www.cement.org/cement-concrete/concrete-materials/cement-types

2020, they found that even within nations there are different establishments that oversee standards. In the UK, the cement industry is regulated by the Environmental Permitting Regulations (EPR) for England and Wales, the Pollution Prevention and Control (PPC) in Scotland, and the Waste Incineration Directive (WID) set by the European Union for all three nations.

These varied and sometimes multiple layers of oversight mean different standards can be set within the same nation, even more so across borders.

Frequency of revisions

Additionally, the frequency of these administrative reviews and procedures also varies by organization and type of standard. This means standards can become outdated as technology and best practices evolve. The revision process for standards can be slow, making it challenging for advancements in cement manufacturing to become accepted and distributed across the industry. This sentiment is echoed by many in the cement industry such as Ian Riley, CEO of the World Cement Association who said in a recent interview with Zawya Media, "Cement and concrete product standards are a major brake on progress in many countries worldwide."[9]

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> IAN RILEY
> CEO, WORLD CEMENT ASSOCIATION

For example, the Environment Agency (EA) is responsible for issuing licences or permits to cement kilns in England and Wales, whereas the Scottish Environment Protection Agency (SEPA) is responsible for approving kilns in Scotland. In order for a cement producer to be granted a permit to burn an alternative or non-fossil fuel, the EA or SEPA requires an environmental assessment to demonstrate that the impact of the factory when using the alternative fuel will be no greater (although in reality, it is less) than when using traditional resources.

These checks and balances are necessary to ensure industry standards are met but a consequence is that while these checks take place, the plants must continue using less sustainable fuel or operational methods. If the industry is to meet its net zero goals in 2050, industry bodies must treat their revision processes with the same urgency the cement producers are invoking to achieve a green transition.

Changing the lens through which standards are adopted

One way for these supervising bodies to speed up their revision process and for cement producers to adopt them is to change the methodology from a 'recipe-based' approach to a 'performance-based' approach.[10]

As the name suggests, in the 'recipe-based' approach, manufacturers follow a precise set of material compositions and proportions in the production process – ensuring that raw materials and their respective proportions are consistent across the board. The primary advantage of this method is predictability, as most manufacturers are aware of these universal expectations and adhere to them.

9 Anoop Menon. *INTERVIEW: 'The decarbonisation challenge lies in the ROI, not fund availability' – World Cement Association CEO.* Zawya Media (October 2023). https://www.zawya.com/en/projects/industry/interview-the-challenge-lies-in-the-return-on-investment-not-fund-availability-i96j8cvu

10 Ellis, Leah, PhD. *Truly, swiftly, and massively decarbonizing cement requires defining it by its performance, not its chemistry.* Sublime Systems (September 2023). https://medium.com/@SublimeSystems/truly-swiftly-and-massively-decarbonizing-cement-requires-defining-it-by-its-performance-not-its-400cf95338ef

However, the recipe-based approach has drawbacks. Its rigidity can stifle innovation, as manufacturers are bound to a fixed set of materials and measuring properties. If newer and more efficient materials or methods emerge, they cannot be incorporated without altering the established standard. This can lead to potential wastage and missed or delayed opportunities for optimization, leading to emissions and potential savings squandered unnecessarily.

Increasingly, there have been calls for standards to shift to a 'performance-based' approach, pivoting the focus from input to output by outlining the desired outcomes or performance criteria the finished cement product must meet. This can range from specific strength and durability metrics to environmental impact benchmarks. The inherent flexibility of this approach gives manufacturers more freedom to innovate, experiment with alternative materials, or adopt novel production techniques.

Each approach has advantages and challenges. Recipe-based standards offer clarity and consistency, but can sometimes hinder progress and innovation. In contrast, performance-based standards, with their emphasis on end results, promote adaptability and evolution but necessitate rigorous quality checks. The preference between the two often hinges on the objectives of the regulatory authority, the industry's current state, and the attributes desired in the final cement product.

The Alliance for Low-Carbon Cement & Concrete (ALCCC), which launched in May 2023 to accelerate the decarbonization of the cement and concrete industry, is spearheading the move to a performance-based model.

Carbon Re supports this effort: We must allow greater flexibility and innovative approaches to cement making if we are to achieve net zero in a timely fashion.

Regulations

The regulatory focus on carbon markets has increased as governments around the world have made pledges to reach net zero carbon emissions. Moving away from the previous light-touch approach, regulators and standard-setters are now taking steps to assess and diminish emissions more effectively. The implementation of taxes on carbon emissions, the reduction of free allowances granted to high emitters, and the establishment of both mandatory and voluntary markets to trade carbon credits have been particularly influential levers of change.

It is likely that carbon markets will be more highly regulated to introduce greater consistency, reinforce the integrity of sustainability disclosures, and respond to stakeholder demand for businesses' sustainability information to be transparent and comparable. As we expect this to happen in the short to medium term, we have looked at forthcoming regulations that will drive decarbonization in the cement industry.

Carbon pricing and taxation

The roll-out of carbon pricing schemes is accelerating, now covering almost a quarter of global greenhouse gas emissions.[11] Many countries and regions have formed their own carbon pricing (or 'carbon taxation') schemes across various sectors.

In May 2023, the European Union rolled out the Carbon Border Adjustment Mechanism (CBAM). By putting a price on the carbon emitted during the production of carbon-intensive goods entering the EU, it is designed to encourage non-EU countries to adopt cleaner industrial processes in their exported goods. South Korea, a major exporter of steel products to Europe, announced plans to extend support for low-emission production methods in order to comply with CBAM and boost their competitiveness. They have also decided to expand the basis for measuring, reporting, and verifying carbon footprints, as well as increased financial support for green projects.

After the UK's withdrawal from the EU, it replaced its participation in the EU Emissions Trading Scheme (ETS) by establishing its own UK ETS at the start of 2021. In the US, where carbon pricing is set at the state level, ETSs are on the rise and now contribute more than one third of the nation's GDP. California set up the first multi-sector ETS (the Cap-and-Trade Program) in the country – which is also the only ETS in the US that covers the cement industry – while 11 northeastern states have formed the Regional Greenhouse Gas Initiative (RGGI) as the nation's first mandatory ETS to limit CO2 emissions from the power sector.

India, another major exporter to the EU, passed the Energy Conservation (Amendment) Bill in December 2022 to set up carbon credit trading schemes for different sectors by 2024. Singapore implemented their carbon tax scheme in 2019, and is currently planning on increasing its carbon price fivefold to $25 per tonne in 2024. China launched its ETS in 2021 for the power sector, which accounts for ~40% of the country's total emissions. It is expected to expand to other carbon-intensive sectors, including steel and construction, in its next phase.

Ripple effects have taken hold more recently, as Indonesia launched the first phase of mandatory carbon trading for coal power plants in February 2023 and Japan began a carbon pricing scheme in April 2023 to encourage companies to curb emissions.

11 *Record High Revenues From Global Carbon Pricing Near $100 Billion.* World Bank (May 2023). https://www.worldbank.org/en/news/press-release/2023/05/23/record-high-revenues-from-global-carbon-pricing-near-100-billion

Carbon credits and trading schemes

Carbon credits have emerged as a prominent way to buy the right to emit one tonne of carbon dioxide (or other equivalent greenhouse gases) from projects that reduce or remove GHGs from the atmosphere, and sell them to other companies as they decarbonize over time. Revenues from carbon taxes and emissions trading systems (ETSs) have reached a record high of $95 billion amidst the challenging context of high inflation, fiscal pressures, and energy crises.[12]

Carbon credits are a tradable permit or certificate that represents the right to emit one tonne of carbon dioxide or the equivalent amount of another greenhouse gas. Projects that create carbon credits include renewable energy projects, energy efficiency projects, and afforestation projects that reduce or remove greenhouse gas emissions from the atmosphere. Carbon markets are established by governments as a means of achieving their carbon reduction targets by trading these credits between businesses and organizations. These markets operate on a mandatory basis, meaning that participating organizations are required by law to participate in the market and to meet certain carbon reduction targets.

The EU ETS is an example of this: Companies that emit large amounts of CO2 are required to purchase a certain number of carbon credits each year. These credits can be obtained through a variety of means, including purchasing them from other companies that have exceeded their carbon reduction targets or by investing in renewable energy projects that result in a net reduction in carbon emissions.

Between 2020 and 2022, two-thirds of the world's biggest companies with net-zero targets were using carbon credits, the biggest users of which were Shell (9.9 million units), Volkswagen (9.6m), and Chevron (6m).[13] Fossil fuel companies and car manufacturers account for more than three-quarters of the offsets purchased by the top 50 companies. In practice, however, most projects fail to deliver on their pledged offsets. It is suggested that only 12% of carbon offsets being sold result in actual emissions reductions.[13]

> **"It is suggested that only 12% of carbon offsets being sold result in actual emissions reductions.**

Free allowances

Carbon credit use in the cement industry is currently unknown. However, in Europe, carbon credits remain unpopular among cement plants based there due to free allowances.

In the EU, cement is one of the industries that receive free allowances or carbon credits from the ETS to protect these sectors from competitive disadvantages that could arise from carbon pricing. This means cement plants are exempt from having to purchase carbon credits as they have a higher allotted amount of carbon they're allowed to emit. This makes it less expensive for cement producers to operate, but creates less of an incentive to buy carbon credits.

Although European cement producers may not feel the immediate pressure to purchase additional carbon credits beyond the EU ETS, as global discussions about climate change intensify the current approach may fall under scrutiny, potentially leading to a re-evaluation of their free allowance system. In this scenario, carbon credits may become crucial for European cement producers.

12 *Record High Revenues From Global Carbon Pricing Near $100 Billion.* World Bank (May 2023). https://www.worldbank.org/en/news/press-release/2023/05/23/record-high-revenues-from-global-carbon-pricing-near-100-billion

13 Gabbatiss, Josh. *Analysis: How some of the world's largest companies rely on carbon offsets to 'reach net-zero'.* Carbon Brief (September 2023). https://interactive.carbonbrief.org/carbon-offsets-2023/companies.html

Unintended consequences of the EU's ETS

Even if a plant does close operations, it can still receive its free allowances in a given calendar year – despite emitting little or no carbon for that year. These allowances can then be used by companies to cover the costs of emitting carbon at other plants or sell to other parties on the secondary market for cash. An investigation by the Oil Price Information Service (OPIS) found that this loophole has been exploited by six European-based plants, operated by five cement industry giants – Holcim Group, CEMEX, Buzzi Unicem, Votorantim Cimentos and Cementos Portland Valderrivas in 2019–2022. These six plants were issued a surplus of €88.2 million in free emissions allowances.[14]

Under the EU ETS, free allowances are issued using a cement plant's historical emissions and production data. Cement plants need to operate their plants at 50% of their maximum capacity to be eligible for the free allowances. Given the value of these credits there is a strong incentive for producers to keep otherwise unprofitable plants going and at higher activity levels than they otherwise would.

Additionally, the metric used to define the amount of free allowances due to a cement producer is the amount of clinker production rather than cement production. A key way to reduce carbon emissions from cement production is to reduce the proportion of clinker in the mix. As such limited progress has been made in the EU on using alternative cementitious materials. Our research shows that the four largest cement producers in the EU have an average ratio of 78% clinker in cement, compared to a global average of 72%.

Voluntary carbon markets

Voluntary carbon markets are similar to ETSs, however, they have no government oversight. These markets allow companies, governments, and other organizations to offset their carbon emissions of their own volition, either to meet their own sustainability goals or to demonstrate their commitment to reducing their carbon footprint.

Although these markets are not directly regulated by the government, highly accredited markets are emerging around the world. One of these is the Gold Standard, a top accreditation verifier for carbon credits that are generated through high-quality, sustainable development projects. In Asia, the Hong Kong Stock Exchange carried out the first batch of carbon credit trades on its new voluntary carbon market in November 2022. Similarly, the Malaysian stock exchange launched a voluntary carbon market at the end of 2022.

Limitations of regulations

Latest figures suggest 28 ETS schemes are in force around the world – with a further 20 systems under development or consideration.[15] The global roll-out of carbon pricing and credit trading markets will continue to accelerate as countries seek to deliver on their commitments to reduce their emissions.

Despite the incentives in place, carbon taxes and ETSs alone are not enough to drive the mass-scale decarbonization the world needs. There is a limit to the price that can be set without deterring interest, and adopting new taxes is politically difficult. Additionally, raising the cost to produce a critical resource like cement would disrupt economies if it is not done so carefully.

Furthermore, ETSs can act as a disincentive for companies if there are voluntary carbon markets

14 *Six Idle EU Cement Plants Received $95 Million in Surplus Free EUAs* . The Oil Price Information Service (September 2023). https://www.opisnet.com/blog/idle-eu-cement-plants/

15 *Emissions Trading Worldwide Status Report 2023*. International Carbon Action Partnership (March 2023). https://icapcarbonaction.com/en/publications/emissions-trading-worldwide-2023-icap-status-report

available. They may choose to purchase carbon credits rather than invest in changing their business practices that avoid emissions in the first place.

A fine balance will have to be made to ensure that companies don't cut corners and eschew responsibility for their emissions while rolling out these regulations in a manner that will not undermine the economy.

ESG reporting requirements

In recent years, there has been increasing societal and regulatory pressure on businesses and manufacturers to measure and disclose their Environmental, Social and Governance (ESG) impact. ESG frameworks serve to incentivize organizations to prioritize and improve practices such as energy usage, waste production, materials usage, and operational emissions. This transparency has proven to be a powerful lever of change. As the adage goes: "You can't improve what you don't measure."

In the early days of ESG, greenwashing was rampant, with many companies exaggerating or embellishing their ESG reports. As awareness and criticism of these false reports intensified over the years, companies have implemented more substantive measures and demonstrable actions to improve their ESG performance. However, due to a lack of comparable data, and a result of different terminologies being used across different companies, comparing the ESG performance across companies remains a challenge.

The need for a standardized ESG reporting process, especially for complex sectors like cement manufacturing, is crucial to hold businesses accountable for their decarbonization practices. Standardization will ensure that all companies, regardless of their size or location, report on the same criteria allowing stakeholders (including investors, regulators, and consumers) to compare and benchmark the ESG performance of companies within the same sector. Applied to cement, this means different plants can be compared and analysed more effectively to create the societal and regulatory scrutiny that will compel them to be more sustainable.

Standardized reporting can also foster collaboration across sectors, as companies with similar operations can share best practices, innovations, and solutions in their ESG disclosures. For example, the cement industry may learn waste management techniques from another sector, amplifying positive environmental outcomes.

> **"Regulation is critical in creating incentives to decarbonise more quickly and completely. While it is possible to discharge CO2 into the atmosphere at no cost, this will continue to be the most economically attractive option. The government should introduce carbon pricing schemes and ensure the carbon price is high enough to drive change.**
>
> IAN RILEY
> CEO, WORLD CEMENT ASSOCIATION

For sectors like cement manufacturing, which have a pronounced environmental, social, and economic impact, adopting a unified ESG reporting framework is not just beneficial — it is essential.

Standardization of ESG reporting

We are seeing moves to standardize ESG reporting across various sectors. It is a monumental challenge, considering all the different sectors and stakeholders involved and the different regimes and jurisdictions.

National standardization

Increasingly, more countries are introducing mandatory sustainability reporting. While it is primarily affecting companies listed on the stock exchanges of advanced economies, smaller markets are also beginning to follow suit.

A 2021 study identified 25 countries that introduced such mandates,[16] primarily targeting financial institutions, state-owned companies, and large listed firms. Below are some of the countries that have brought in mandatory reporting in recent years.

- **United Kingdom:** In April 2022, the UK introduced two mandatory ESG disclosure laws. These regulations mandate specific companies, primarily those with over 500 employees and significant turnovers, to provide climate-related financial disclosures in their strategic reports.

- **European Union:** The EU had the Non-Financial Reporting Directive (NFRD) that required certain large companies to disclose ESG information. However, in 2023, the NFRD was superseded by the Corporate Sustainability Reporting Directive (CSRD), expanding the scope to approximately 50,000 companies, representing 75% of the EU's company turnover.

- **United States:** As of this writing, there are no federal-level mandatory ESG disclosure requirements. However, in May 2022, the US Securities and Exchange Commission (SEC) proposed amendments to promote consistent ESG information for investors, targeting funds and advisers emphasising ESG factors.

- **Canada:** In its 2022 budget, the Canadian federal government announced plans to introduce mandatory climate-related reporting for federally regulated banks and insurance companies by 2024, aligned with the TCFD framework.

The ripple effect of these regulations means even small and medium enterprises (SMEs) are beginning to feel the pressure to disclose their ESG metrics. As large corporations request sustainability data from across their supply chains, SMEs will increasingly need to measure their own environmental and social impacts. The study shows that regulations are successfully pushing mandatory ESG reporting beyond just large, publicly listed companies, promoting sustainability at all levels.

International Sustainability Standards Board (ISSB)

Relating specifically to the Sustainability strand of ESG, a new supra-national body has been created to put forward common reporting requirements on all global industries and sectors. The International Sustainability Standards Board (ISSB) is poised to play a pivotal role in standardising sustainability disclosures, ensuring that these reports are efficient and effective in meeting the needs of the global market, in particular the requirements of investors and the financial markets.

The ISSB has four primary goals:

1. Establish standards for a global sustainability disclosure baseline
2. Meet the informational needs of investors
3. Assist companies in offering comprehensive sustainability data to global capital markets
4. Ensure compatibility with jurisdiction-specific disclosures and those targeting a wider range of stakeholders

However, one of the challenges the ISSB aims to tackle is the fragmented landscape of voluntary sustainability reporting. Such fragmentation

16 Philipp Krueger, Zacharias Sautner, Dragon Yongjun Tang, Rui Zhong. *The Effects of Mandatory ESG Disclosure around the World.* ECGI (May 2021). https://www.ecgi.global/working-paper/effects-mandatory-esg-disclosure-around-world

adds to the cost, complexity, and risk for both companies and investors.

The ISSB's efforts to develop sustainability disclosure standards have garnered support from major international entities, including the G7, G20, IOSCO, the Financial Stability Board, and finance authorities from over 40 jurisdictions. Its work is an extension of existing market-led, investor-centric reporting initiatives. This includes frameworks and standards set by organizations like the Climate Disclosure Standards Board (CDSB), the Task Force for Climate-related Financial Disclosures (TCFD), the Value Reporting Foundation, SASB Standards, and the World Economic Forum's Stakeholder Capitalism Metrics.

Standardization of ESG reporting in the cement industry

ESG reporting is currently not standardized in the cement industry. Although many companies, particularly the largest players, publish comprehensive and detailed ESG reports, they are all voluntary and vary to some extent. This diminishes their comparability and efficiency, and tends to benefit their own stakeholders rather than becoming opportunities for collaboration with other cement plants by sharing ideas for process improvement.

However, in 2019 the Global Cement and Concrete Association (GCCA) introduced guidelines that provide reporting frameworks to cement manufacturers. Their Sustainability Guidelines and Charter are designed to monitor and enhance the sustainability performance of the global cement and concrete sectors.[17]

The guidelines encompass seven key areas with specific Key Performance Indicators (KPIs). Full member companies are mandated to monitor and report their sustainability performance based on these KPIs.

The GCCA guidelines cover important operational areas:

- **Health and safety:** Ensurement of contractor and driver safety as a top priority. The guidelines focus on monitoring and reporting performance in all workplaces, with the aim of achieving zero harm for the many contractors, drivers, engineers, and other individuals involved in cement and concrete plant operations.
- **CO2 monitoring:** Management and reduction of CO2 emissions. These guidelines set emission reduction targets, energy efficiency, use of alternative fuels and breakthrough technologies such as CCUS to minimize the plant's carbon footprint.
- **Co-processing:** The responsible use of raw materials and alternative fuels in cement production.
- **Emissions measurement:** Uniform monitoring and reporting of emissions data, including dust, NOx, SO2, VOC, heavy metals, and dioxins/furans.
- **Water management:** Efficient water management strategies to avert water scarcity, with a particular focus on water-stressed areas.
- **Quarry rehabilitation:** Responsible quarry management and environmental rehabilitation. This includes biodiversity management, land stewardship, and site restoration.
- **Social impact:** Standards for community engagement, social investment, and respect for human rights across cement operations and the value chain.
- **Transparency:** Verified data and production targets, and publicly published reports. The GCCA consolidates this data for public communication.

17 *Sustainability Charter and Guidelines*. GCCA (October 2019). https://gccassociation.org/sustainability-innovation/sustainability-charter-and-guidelines/

Customer demand

The cement manufacturing sector is increasingly being pressured by its customers to adapt and innovate to reduce its sizeable environmental impact. These customers, often construction companies, are not only demanding products that are sustainable but also durable, efficient, and interoperable, all at the right price. This move towards sustainable products comes as a result of increased pressure from investors, regulators, and their own clients. Some of the biggest clients of those projects are government and public sector buyers, who are under pressure to present "green" credentials.

This shift in customer mindset is driving cement manufacturers to rethink their production processes. Beyond traditional methods, they must innovate and adopt greener alternatives to meet these new demands.

Customer demand for low-carbon cement

Many construction companies and their customers now prefer, and specify, cement products that incorporate lower carbon solutions or use less energy in their production. Additionally, regulatory bodies and industry associations are setting stricter standards for cement products, demanding reduced carbon footprints and minimized environmental impact.

To meet these requirements, cement manufacturers are exploring alternative raw materials, investing in energy-efficient machinery, and researching innovative production techniques. For example, the use of fly ash, slag, and natural pozzolans as supplementary cementitious materials (SCMs) is gaining traction. These materials not only reduce the carbon footprint of cement but also enhance its durability and performance. We will be exploring existing and new technologies for decarbonized cement later in the paper.

For cement manufacturers, these changes represent both a challenge and an opportunity. Although adapting to new demands and specifications requires investment in research and development, it also opens doors to new markets and customer segments. Manufacturers that prioritize environmental performance stand to gain a competitive edge, enjoying increased customer loyalty and potentially higher profit margins.

Customer specifications along the cement production chain

The cement production chain:

The production chain for cement is a comprehensive process that involves multiple stages, from mining to final use in buildings. Throughout this production chain, continuous quality checks are performed to ensure the final product meets the desired specifications and standards. Additionally, with growing environmental concerns, many cement manufacturers are now incorporating sustainable practices, such as using alternative fuels and reducing CO2 emissions, throughout the production process. Customer specifications have a major role to play in this.

Regulations on low-carbon cement specifications

Regulators across the world are actively working to evolve best practices around cement specification in the construction sector. As of this writing in November 2023, the following regulatory bodies are updating guidance and regulation on these requirements:

- The Construction Products Regulation (CPR) is currently under revision by the European Commission. The CPR sets out the essential requirements for construction products sold in the European Union, particularly in sustainability and durability. The revised CPR is expected to be finalized in 2024, and come into force in 2025.
- The UK Government is developing a new regulatory framework for construction products based on the CPR. The new framework is expected to come into force in 2025.
- The American Society for Testing and Materials (ASTM) is a voluntary standards development organization that is currently developing new specifications for cement products, such as low-carbon cement and sustainable cement.
- The International Organization for Standardization (ISO) is developing new specifications that will include requirements around greenhouse gas emissions, conservation of natural resources, waste management, and social & economic impacts. The standard is expected to be published in 2024.

Key initiatives for low-carbon cement and concrete

A number of cross-industry initiatives to redefine cement and concrete specifications have been set up to help reduce the carbon intensity of both materials.

In 2021, the GCCA in collaboration with the World Economic Forum introduced the Concrete Action for Climate (CAC). This coalition of businesses, governments, and non-profit organizations champion the goal of achieving net-zero concrete by the mid-century mark. The initiative's mission revolves around aligning supply and production processes with international climate objectives. Furthermore, it aims to conceptualize and promote suitable policy mechanisms to boost demand for eco-friendly cement and concrete and to encourage a circular approach within the industry.

The First Movers Coalition led by the World Economic Forum is a partnership of over 100 companies across seven high-emission sectors, aiming to decarbonize heavy industry by fostering early markets for groundbreaking clean technologies. At the 2022 COP27 event, The Coalition pledged to buy "a minimum of 10% (volume-wise) of their annual cement/concrete as near-zero cement/concrete, incorporating any SCMs by 2030, and phasing out fossil-based SCMs by 2035."[18]

In 2022, the international organization Climate Group unveiled its Concrete Zero initiative. In conjunction with prominent members of heavy industry, the Group is working to establish a market for near-zero concrete. Members of this initiative have committed to adopt 30% low-emission concrete by 2025, increasing to 50% by 2030.[19] The Group characterizes low-emission concrete based on its embodied carbon intensity relative to its strength class. For example, the weakest strength class of concrete is labelled low-emission if its embodied carbon is under 100 kg CO2eq/m3, whereas the highest strength class must not exceed 270 kg CO2eq/m3.

Several other initiatives are also in motion to enhance energy efficiency in cement manufacturing. Among these is the **Plant Evaluation Gap Analysis and Support Service (PEGASUS)** programme, orchestrated by the World Cement Association. Additionally, the

18 *Private Sector Strategies*. International Energy Agency. https://www.iea.org/energy-system/industry/cement

19 *Creating a market for net zero concrete*. Climate Group. https://www.theclimategroup.org/concretezero

GCCA **Getting the Numbers Right (GNR)** initiative serves as a reporting database, aiding in industry benchmarking and the GCCA's Innovandi programme accelerates the development and commercialization of decarbonization technologies by fostering innovation within the sector.

Low-carbon construction projects

Encouragingly, an increasing number of construction projects are specifying materials that have been produced with reduced carbon emissions. More projects with similar sustainability goals will increase as more manufacturers adopt decarbonization methods, making these materials with lower carbon footprints available on the market.

Below we list some notable examples of large-scale projects that have specified low-carbon cement or concrete.

Amazon HQ2 (United States)

In National Landing, Virginia, the construction of a new major site for Amazon's secondary headquarters (HQ2, formally named Metropolitan Park) is taking place in an existing urban renewal and development project. The first phase involved the redevelopment of a block of vacant warehouses into retail space, open spaces, and two new LEED Platinum-certified buildings. Suppliers Miller & Long and Vulcan Materials delivered an estimated 81,467 cubic meters of concrete made with CarbonCure technology, saving approximately 1,144 tonnes of CO2.[20]

London HS2 (United Kingdom)

In 2020, as part of its ambition to build the most sustainable high-speed railway in the world, contractors of the High Speed 2 (HS2) project in London announced that they had begun using a new low-carbon concrete product, which provides a reduction of 42% in CO2 in comparison to a standard concrete.[21] In doing so, the project completed the largest-ever UK pour of low-carbon concrete on the London Euston train station site in 2022.

Earth Friendly Concrete (EFC), a material that reduces the amount of carbon embedded into the concrete, saved the company over 76 tonnes of CO2. The EFC product, supplied by Capital Concrete, has been used as a foundation slab that will support polymer silos used for future piling works at the north of the Euston station site. Whilst the foundation is only temporary, historically it would have been constructed with a more traditional cement-based concrete with a higher carbon footprint.

Paris 2024 Olympic Games (France)

The organizers of the 2024 Olympic Games in Paris have taken a strategic approach to ensuring low-carbon construction. Among the suppliers, Ecocem is set to provide its new ultra-low carbon cement for the Athletes' Village, as well as the Grand Paris Express, the largest transport project in Europe.[22] Ecocem Ultra is expected to save 3382.35 tonnes and 34.56 tonnes of CO2 in each project.[23]

20 *Amazon HQ2*. Carbon Cure. https://www.carboncure.com/projects/amazon-hq2/

21 *HS2 completes largest ever UK pour of carbon-reducing concrete on Euston station site.* HS2 (October 2022). https://mediacentre.hs2.org.uk/news/hs2-completes-largest-ever-uk-pour-of-carbon-reducing-concrete-on-euston-station-site

22 *Ecocem to supply ultra-low carbon cement to the Athletes Village and Grand Paris Express.* Building Ireland (November 2021). https://buildingirelandmagazine.com/ecocem-to-supply-ultra-low-carbon-cement-to-the-athletes-village-and-grand-paris-express/

23 *Projects.* Ecocem Global. https://www.ecocemglobal.com/project/

Technologies

The industry has recognized the scale and importance of decarbonizing cement production. Cement companies are among the biggest players in announcing pledges to reduce net zero emissions by 2050.[24] To help producers accelerate their pledges into action various cement industry bodies have developed decarbonization roadmaps, providing leadership and guidance on available solutions.

Some of these decarbonization roadmaps include:

- "Roadmap to Carbon Neutrality" from the Portland Cement Association (PCA) in the US, published in October 2021, which covers cement production, building with concrete and the full value chain to end-of-life.[25]
- "2050 Roadmap" from Cembureau in Europe with a similar broad scope and focus on net zero by 2050, published in May 2020.[26]
- "UK Concrete and Cement Industry Roadmap to Beyond Net Zero" from the Mineral Products Association (MPA) in the UK, published in Oct 2020.[27]
- "2050 Cement and Concrete Industry Roadmap for Net Zero Concrete" from the Global Concrete and Cement Association (GCCA), and their recognition of the importance of 2030 goals.[28]

Although each of these roadmaps differs slightly, each recognizes that there is no single solution that will act as a silver bullet for the industry. Cement producers will need to implement an array of technologies, both established and emerging, to reduce their process and fuel-derived emissions.

In the next section, we outline some of the technologies available to cement producers now as well as emerging technologies that will likely be part of the toolkit for the industry in the coming decades.

Established technologies

Fortunately, there are a number of proven, mature decarbonization technologies that are already on the market that can be implemented today.

Alternative fuels

Replacing fossil-fuel derived energy sources (such as coal and petroleum coke) with alternative fuels (such as biomass, refuse-derived fuel [RDF], and municipal solid waste) is a reliable and tested method of reducing carbon emissions in cement production. Minor investment is required to equip plants to process alternative fuels, making the technology attractive to producers. The current thermal substitution rate (TSR), or percentage of alternative fuels in the fuel mix, varies globally with European producers at the forefront boasting an average TSR of 60%, with some running on 100% alternative fuels.[29]

24 *Net Zero by 2050: A Roadmap for the Global Energy Sector.* International Energy Agency (October 2021). https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

25 *Roadmap to Carbon Neutrality.* Portland Cement Association (PCA) (October 2021). https://www.cement.org/docs/default-source/roadmap/pca-roadmap-to-carbon-neutrality_10_10_21_final.pdf

26 *2050 Roadmap.* Cembureau (May 2020). https://cembureau.eu/media/kuxd32gi/cembureau-2050-roadmap_final-version_web.pdf

27 UK Concrete and Cement Industry Roadmap to Beyond Net Zero. Mineral Products Association (MPA) (October 2020). https://www.mineralproducts.org/MPA/media/root/Publications/2020/MPA-UKC-Roadmap-to-Beyond-Net-Zero_Oct20.pdf

28 *2050 Cement and Concrete Industry Roadmap for Net Zero Concrete.* The Global Concrete and Cement Association (GCCA) https://gccassociation.org/concretefuture/2020-2030-the-decade-to-make-it-happen/

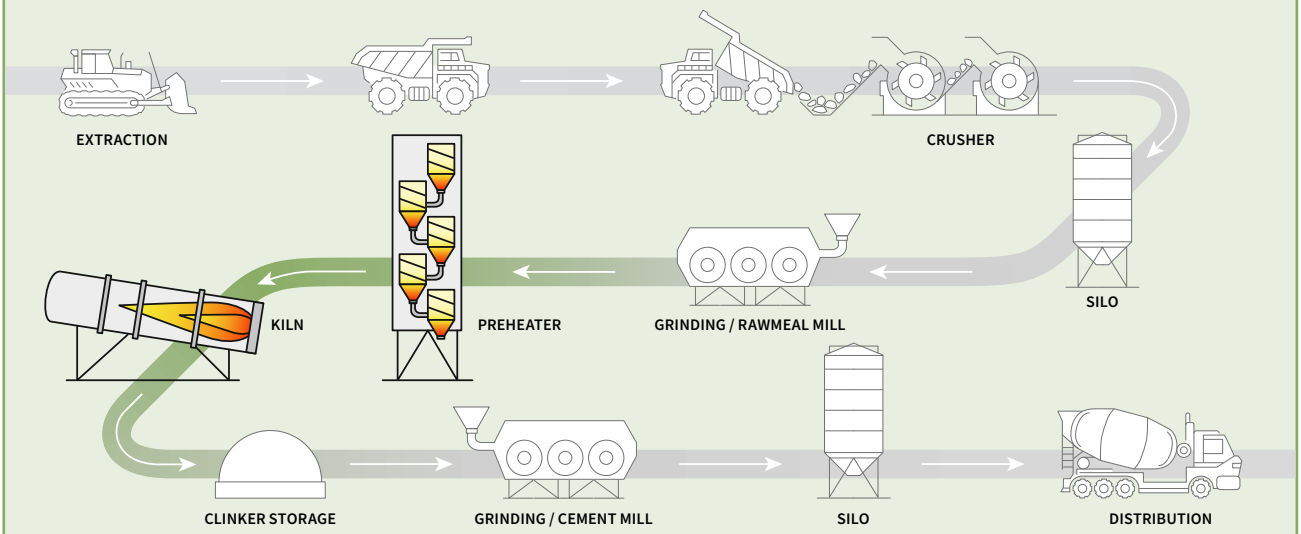
29 Klappholz, Sol. *Holcim launches Europe's first calcined clay low-carbon cement operation.* World Cement (Feb 2023). https://www.worldcement.com/europe-cis/13022023/holcim-launches-europes-first-calcined-clay-low-carbon-cement-operation/

Although alternative fuels hold significant promise, their adoption in the industry is not without challenges. Increasing the TSR in fuel mixes can decrease the thermal efficiency in the kiln, therefore requiring more fuel to reach the same temperatures. Furthermore, it is difficult to find commercially available alternative fuels.

Some local governments provide incentives for cement producers to use waste materials as a means of disposal without sending waste to landfills. RDF and municipal solid waste in particular are renewable sources of combustible components from everyday rubbish. However, these are not inherent solutions to reducing emissions as burning waste can be harmful to the environment and to local communities.

As well as a decrease in thermal efficiency, the composition of the alternative fuels will also affect the production process in different ways, due to volatile contents and particulate size.[30] All these different interactions from alternative fuels add complexity to decision-making on plant control parameters. Research conducted at Carbon Re suggests these challenges can be addressed through AI-powered technologies, calculating optimal operational conditions and fuel mixes to prevent blockages caused by alternative fuels, thereby increasing their use and efficiency.[31]

The raw materials of cement, limestone and clay, are mined at local quarries and crushed in preparation for the preheating kiln. This combined “raw meal” is heated to around 900°C in a process called calcination: a chemical reaction in which the calcium carbonate in the limestone is converted into calcium oxide. Carbon dioxide is released as a part of this reaction. The CO2 produced during calcination accounts for 55% of cement’s carbon emissions. The “calcined raw meal” is then added to a rotating kiln and heated to an extreme temperature (1450°C) to produce “clinker”, the key constituent of cement. Fossil fuels are burnt to produce the high temperatures required in the preheater and kiln. This process accounts for 40% of CO2 emissions in cement production, with the remaining 5% for electricity in grinding materials.



30 Impact of alternative fuels on the cement manufacturing plant performance: an overview. Procedia Engineering 56 (2013) https://pdf.sciencedirectassets.com/278653/1-s2.0-S1877705813X00074/1-s2.0-S187770581300492X/main.pdf

31 Price, Buffy. *Growth in waste derived fuels* (May 2023). https://carbonre.com/growth-in-waste-derived-fuels/

Energy efficiency

Energy efficiency remains one of, if not the most important emissions reduction lever for the industry to achieve its net zero goals by 2030. Since the 1960s, the cement industry successfully halved its energy efficiency, with 20% of these reductions happening only in the last 30 years.[32,33] The efficiency improvements to date have predominantly been achieved through the best available technologies, and further improvements can be made through the modernization of hardware, upgrades, and artificial intelligence.

Continually introducing hardware innovations drives energy efficiency improvements, however, in the cement industry, this is typically done incrementally over long periods of time. Hardware in cement plants on average has a lifetime of 20–30 years, and 30–50 years in kilns. As such, equipment is typically modernized every few years, and only when required.

On the other hand, deploying software solutions to introduce process improvements can be done quickly, sometimes without capital investment, and without requiring the installation of new process control systems across the cement plant. Software solutions that deploy AI and machine learning further allow plants to control the many variables of cement production, allowing for optimal and more efficient processes, and reducing carbon intensities in fuel and electricity usage.

Substitute cementitious materials (SCMs)

Substitute Cementitious Materials (SCMs), or any material that can replace clinker in cement, are among the most well-known and proven decarbonization technologies available to the cement industry. The production of clinker is the most carbon-intensive process in cement manufacturing, accounting for over 80% of cement production emissions. Therefore, by reducing the ratio of clinker in cement by even a few percentage points, the carbon intensity of the cement can be significantly reduced.[34]

Worryingly, the global average clinker-to-cement ratio has increased in recent years from 0.66 in 2015 to 0.71 in 2023.[35] Add sentence between: In Europe, the average clinker factor is even higher at 0.74.[36] To align with net zero targets, the International Energy Agency (IEA) advises that a global average clinker-to-cement needs to decrease to 0.65 by 2050.

At present, the most commonly used SCMs are waste products from other fossil fuel-powered processes, such as fly ash from coal-fired power stations and ground granulated blast furnace slag (GGBS) from steel plants. However, as these industries improve their waste management in line with their own net-zero targets, the availability of these substitutes will decrease in the coming decades. Fortunately, other materials such as natural pozzolans (volcanic ash), limestone, burned oil shale, and calcined clay can be scaled up in place of slag and fly ash.

One challenge for the use of SCMs is the limitation in their use based on location, this applied both to the SCMs used most frequently today and the other materials that may be scaled in the future. Currently, it is cement producers whose sites are in close proximity to coal-fired power stations and steel plants that benefit the most. For example,

32 *The role of cement in the 2050 low carbon economy.* Cembureau (September 2018). https://lowcarboneconomy.cembureau.eu/wp-content/uploads/2018/09/cembureau-full-report.pdf

33 *Roadmap to carbon neutrality.* PCA (October 2021). https://www.cement.org/docs/default-source/membership-2020/pca_roadmap-to-carbon-neutrality_jan-2022.pdf

34 Passaro, Fabio. Concrete policies to underpin the cement transition. Climate Bonds Initiative (March 2023) https://www.climatebonds.net/files/reports/cbi-cement-policy.pdf

35 *Technology Deployment.* International Energy Agency. https://www.iea.org/energy-system/industry/cement

36 Clinker Substitution. Cembureau (Accessed December 2023). https://lowcarboneconomy.cembureau.eu/5-parallel-routes/resource-efficiency/clinker-substitution/

Indian producers Dalmia and Shree Cement have a clinker-cement ratio of 0.61 and 0.64 respectively.

Despite these challenges, SCMs remain one of the most widely accepted decarbonization solutions as their embodied carbon emissions are lower than that of clinker, and they complete the circular economy of the process with industrial waste going back into the production line.

Emerging technologies

Algae-based biocomposite cement alternative

Inspired by coral reefs, a team of biotechnology and engineering professors at the University of Colorado Boulder created a cement-free material known as bio-cement, by growing biomineralizing microalgae in bioreactors. Bio-cement is then mixed with aggregates to form cement-free building material blocks akin to concrete blocks.

This process eliminates the use of fossil fuels and process emissions, however the scalability of this technology is yet to be proven, as current volumes are limited although commercial production is underway.[37]

Carbon capture utilisation and storage (CCUS)

Unlike other energy-intensive industries (such as steel), the chemical process of producing cement inherently releases carbon dioxide when the raw materials undergo molecular changes in the kiln. As such, technologies like Carbon Capture Utilisation and Storage (CCUS) that can capture and store carbon dioxide from industrial processes will be particularly vital. Cement can never become a net zero product without CCUS mitigating its intrinsic process emissions.

Pilot demonstrations have shown promise with this technology, showing that CO2 separation yields up to 99% depending on the technology. The potential impact of CCUS is immense, however, the capital expenditure required to install a CCUS facility is unclear at present, although there are estimations that retrofitting an existing CCUS plant could cost between €100 ~ €300 million.[38] Additionally, the power consumption of a cement plant may increase by 50 ~ 120% per plant if implemented with CCUS technology.[39] There are currently no industrial-scale facilities functioning globally.

Although CCUS will not be here on the required scale in the next decade, investment and development in the technology is critical to find a way to produce cement without emitting harmful carbon emissions. Our modelling suggests the resulting effective cost to abate carbon emissions would be in the range of €60 to €135 per tonne CO2 once the technology is mature.[40] This is within the range of expectations for carbon prices for markets with an Emissions Trading Scheme in place, suggesting that the technology may be commercially viable in the long term.

Chemical additives

Chemical additives offer another pathway to lower the carbon intensity of cement and concrete, decreasing their carbon footprint by increasing grinding efficiency, requiring less water, less clinker, and less cement to produce concrete. The aim of these additives is to modify and enhance the properties to boost quality.

37 Dreith, Ben. *Prometheus Materials uses algae-based cement to make masonry blocks*. Dezeen (June 2022). https://www.dezeen.com/2022/06/07/prometheus-biocomposite-cement-blocks/

38 *The role of cement in the 2050 low carbon economy*. Cembureau. https://lowcarboneconomy.cembureau.eu/wp-content/uploads/2018/09/cembureau-full-report.pdf

39 *The energy needs of the EU cement industry*. Cembureau. https://cembureau.eu/media/4sdltc0l/230605-tno-study-energy-assessment-for-ccus-eu-cement-sector-key-findings.pdf

40 *Three technologies to reduce climate change*. Carbon Re (February 2023). https://carbonre.com/three-technologies-to-reduce-climate-change/

GCP Applied Technologies, one leading supplier of proprietary additives, states that its additives can reduce emissions by 14%, an effective 150 kg CO2/t.[41] The commercial sensitivities about chemical formulations and processes mean that objective data is hard to obtain. According to GCP "The myriad cement chemistries and morphology variables available – combined with the varying objectives and constraints in each market means there is a vast number of permutations when it comes to choosing which cement additives to use. It can also be difficult to predict the performance of combining multiple additives together."[42] It is an interesting area of technology and further insight is needed. It will likely be enhanced further by AI and machine learning to resolve the complex decisions required on the right additives to use for each construction application.

Electrolysis

Electrolysis is a different approach to clinker production that may replace the heating process altogether. Normally, clinker is formed by sintering limestone and aluminosilicates, which causes decomposition while CO2 is released. Electrolysis, on the other hand, applies a voltage across limestone dissolved in water to form calcium hydroxide. Silicon dioxide is then added to the calcium hydroxide to form alite, one of the four mineral phases in clinker.

Although CO2 is still emitted, the benefit of electrolysis is that the emissions are purer, making CCUS more effective. Hydrogen is also formed as a side product, which could be used as a fuel elsewhere in the plant. This process can also use

41 *GCP Functional Additives.* GCP Applied Technologies. https://gcpat.com/en/products/gcp-functional-additives

42 *Decarbonizing the Cement Industry.* GCP Applied Technologies.

abundantly available non-carbonate materials to eliminate the emissions associated with cement production.[43] The chemical reaction also avoids the need for high temperatures, although it has only been tested in laboratories.[44]

The main concern with electrolysis is that it has yet to be proven on any kind of industrial scale, as it has yet to be trialled out of experimental labs at the Massachusetts Institute of Technology (MIT). There is therefore limited understanding of the cost, scalability, and other potential drawbacks. As such, there is a possibility electrolysis would be energy-intensive, requiring electricity from renewable sources for it to be a true decarbonization solution.

Graphene

Graphene is a form of carbon molecule that consists of a single layer of atoms arranged in a hexagonal lattice. These nanoplatelets of graphene can strengthen concrete mixes by decreasing porosity, increasing crystallinity and acting as a nucleation surface. The resulting concrete is significantly higher strength, hence studies suggest between 20 ~ 50% less concrete may be required to meet the same load requirements.[45]

However, graphene can cost between $67,000 ~ $200,000 per tonne, compared to just $50 for the same quantity of cement. Despite its high cost per tonne, trials suggest the use of graphene could ultimately be cost-effective as the reduced quantities of concrete needed for the same strength could balance out the high cost of graphene: only 1.9kg of graphene is reportedly needed for every 20,000 kg of concrete.

Additional research on graphene, including the quality metrics required to achieve desirable performance results, as well as a significant increase in graphene production will be needed in order for the cement industry to take advantage of this technology.

Green hydrogen fuel

Hydrogen, when generated through the process of water electrolysis and powered by renewable electricity, can be a carbon-neutral fuel that can replace fossil fuels. Green hydrogen is in high demand as a renewable energy source. It is perceived as a primary decarbonization method to eliminate fossil fuel use from shipping, aviation, road transportation, chemical production, and steel production. Similarly, in cement production, replacing fossil fuels entirely with green hydrogen would eliminate thermal carbon emissions.

Feasibility studies are still being conducted to confirm the viability of hydrogen fuel for cement production. Cement production through green hydrogen is not the most efficient use of renewable electricity as each stage of the process incurs efficiency losses that drive up its own cost. Furthermore, the flame produced by hydrogen does not have the same chemical composition or shape as those produced by coal-based fuels, which means plants will need to develop a new kiln adapted to this difference. Additionally, in order to generate hydrogen that is truly 'green', specialized infrastructure as well as sustainable transport and storage methods will be required. The total capital investment would therefore go beyond refitting the kiln, requiring a high cost to run a hydrogen-fuelled cement plant.

This has not prevented cement manufacturers from trialling the use of hydrogen and green hydrogen in their production line, specifically as part of a fuel blend. For example, CEMEX is using hydrogen in their fuel mix in all their European cement plants (although it is not specifically

43 *Low carbon-cement without comprimise.* Sublime Systems. https://sublime-systems.com/technology/

44 Doyle, Amanda. *Producing cement using electrolysis.* The Chemical Engineer (October 2019). https://www.thechemicalengineer.com/news/producing-cement-using-electrolysis/

45 Baker, James. *Getting Graphene Ready: Adopting the Manchester Model of Innovation.* Graphene (2022).

green), and Hanson/Heidelberg are running pilots for green hydrogen in the UK. The IEA estimates that from the 2040s, hydrogen may account for 10% of the thermal energy needs for cement production.[46]

Kiln electrification

Kiln electrification is another potential plant upgrade that can result in the complete reduction of thermal carbon emissions. Although it is incredibly challenging for electric power alone to reach the high temperatures needed in cement production, the CemZero project in Sweden has demonstrated the ability of electricity to feasibly heat kilns to the required temperatures.[47]

As of 2023, a number of kiln electrification projects are currently in development. Coolbrook is the current industry leader, expected to have its electrification technology available by late 2024 in partnership with CEMEX and UltraTech cement.[48] Additionally, in 2022, CEMEX partnered with Synhelion to explore solar-powered clinkerization, replacing fossil fuel-derived energy with solar-powered electricity.[49]

The scalability of this technology is limited by expensive capital investment, as well as the cost and availability of 100% renewable energy. There are also questions about the ability of electricity to supply enough energy for the sintering phase in the kiln, however, other emerging technologies (such as electrolysis, as discussed later) could potentially fill in these gaps.

46 *Net Zero by 2050: A Roadmap for the Global Energy Sector.* International Energy Agency (October 2021). https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

47 Passaro, Fabio. Concrete policies to underpin the cement transition. Climate Bonds Initiative (March 2023) https://www.climatebonds.net/files/reports/cbi-cement-policy.pdf

48 Schumacher, Jenni. *Coolbrook launches RDH technology that CEMEX will use to cut CO2 from cement production.* Coolbrook (May 2022). https://coolbrook.com/news/coolbrook-launches-rdh-technology-that-cemex-will-use-to-cut-co2-from-cement-production/

49 *CEMEX and Synhelion achieve breakthrough in cement production with solar energy.* CEMEX (February 2022) https://www.cemex.com/w/cemex-and-synhelion-achieve-breakthrough-in-cement-production-with-solar-energy

Commercial advantages

Although some cement companies are nationalized or owned by governmental bodies, the majority of cement companies are commercial. The industry is highly competitive, capital intensive, has low profit margins, and is made up of networks of regional markets. There is therefore a great incentive for cement companies to use their decarbonization strategies to create tangible commercial advantage where possible.

The key areas in which cement companies can achieve commercial advantages are:

- Cost reduction
- Differentiation and reputation enhancement
- Price premiums on low-carbon products

Cost reduction

In many cases, doing the right thing for the environment can mean doing the right thing for the bottom line. Efficiency improvements, waste reduction, and resource optimization (particularly in raw materials and fuel) can just as drive cost savings, profitability, and competitive advantage as they can preserve the environment.

Previously, the commercial strategy of producers had been to minimize the cost per tonne of cement by maximizing production capacity. However, after the cement boom of the 1990s and 2000s, overcapacity issues have made economies of scale no longer a viable option. Instead, optimization of production costs has become the favoured commercial strategy.

Of these production costs, energy requirements represent the largest variable cost, accounting for around 35 – 40% of all short-run operational expenses.[50] In fact, the cement industry has one of the highest share of energy costs in the hard-to-abate industries, with more than 12% in 2017; double that of the steel industry.[51] As such, through energy efficiency or reductions in fuel use, cement producers can reduce their operational expenses as well as their carbon emissions. Furthermore, in regions with ETS schemes, producers can also lower the amount of carbon tax paid.

Differentiation and reputation

Deploying decarbonization solutions and offering low-carbon products can also deliver a commercial advantage to producers by positively impacting their reputation and differentiation against their competitors. Proactive climate strategies increase a company's reputational capital[52] by increasing competitive positioning, heightened visibility, and favourable perception among current and potential employees and investors. Companies implementing decarbonization solutions are racing to establish themselves as the first mover on climate action in the cement industry.

Moreover, given the localized nature of cement markets, there is an opportunity for companies in each regional market to leverage this reputational advantage. Conversely, the failure to set ambitious and attainable climate targets (and act on them) may result in a loss of investment from financiers

50 *Investment, Carbon Pricing and Leakage: a cement sector perspective. Climate Strategies* (September 2011) https://climatestrategies.org/wp-content/uploads/2011/09/cs-investment-carbon-pricing-leakage-cement-sector-perspective-cook.pdf

51 Passaro, Fabio. *Concrete policies to underpin the cement transition.* Climate Bonds Initiative (March 2023) https://www.climatebonds.net/files/reports/cbi-cement-policy.pdf

52 Johnson, M.P., Rötzel, T.S. & Frank, B. *Beyond conventional corporate responses to climate change towards deep decarbonization: a systematic literature review.* Management Review Quarterly (January 2023). https://doi.org/10.1007/s11301-023-00318-8

looking for green investments, in addition to reputational damage.[53]

Price premiums on low-carbon products

The demand for low-carbon cement will only increase as more developers and construction companies set ambitious climate targets, and join initiatives such as ConcreteZero in which members commit to using 30% low-emission concrete by 2025, and 50% by 2030.

It is estimated that future "climate neutral" cement will cost 70% – 95% more than today's carbon-intensive cement.[54] To make a compelling business case for cement producers to invest in decarbonization technologies, they will need to put a price premium (or 'green premium') on these low-carbon products.

There have been many studies suggesting that consumers are willing to pay a green premium. Although these studies suggest less willingness to spend more than an additional 10% for sustainable products.[55] Given that the cost of concrete in a typical building is around 5%, a green premium on cement and concrete will not significantly affect the final cost of a new building.[56] The challenge for producers is less focused on pricing their green products but rather finding a market in which to sell them.

Public procurement policies

One substantiated method of creating initial markets for low-carbon or 'green' cement products is through public procurement schemes. Such as the EU's Green Public Procurement (GPP) policy, which encourages public authorities to make environmentally conscious purchases and decisions.

Public procurement accounts for up to 40% of the global demand for cement, and represents a high share of consumption in key industries such as construction and infrastructure.[57] Introducing similar mandatory criteria would enable preferential spending in government budgets. Although it is a voluntary legislation, the GPP requires every member EU state to set national budgets for purchasing goods, services, and works with reduced environmental impacts. Aligning GPP standards with the EU taxonomy will ensure consistency of green public investment.

Additionally, contract-for-difference (CfDs) can require buyers to pay the seller the difference between the value of a purchased product at contract time and its current value, which can also bolster a market for green cement.

Cement producers that deploy decarbonization strategies will likely gain a commercial advantage as they work in tangent to reduce operational costs, improve their differentiation & reputation, and customers increasingly prioritizing and being incentivized to make sustainable purchases. The companies that lag behind in offering low-carbon products will risk losing market share. In this evolving industry, it will be the progressive cement plants that embrace decarbonization that will come out ahead in the way of cost savings and securing financial gains in the future.

53 Handley, Lucy. *Why fear of a bad reputation could be what really makes firms focus on climate change*. CNBC (November 2021). https://www.cnbc.com/2021/11/11/cop26-fear-of-a-bad-reputation-could-be-what-really-makes-firms-change.html

54 *Gör betongen klimatneutral*. UNT (2023) https://unt.se/bli-prenumerant/artikel/lywgqz9j/unt-1m1kr_s_23

55 Mehdi Miremadi, Chris Musso and Ulrich Weihe. *How much will consumers pay to go green?*. McKinsey Quartely (October 2012). https://www.mckinsey.com/capabilities/sustainability/our-insights/how-much-will-consumers-pay-to-go-green

56 *Scaling Low-Carbon Design and Construction with Concrete: Enabling the Path to Net-Zero for Buildings and Infrastructure*. World Economic Forum (March 2023).

57 Passaro, Fabio. *Concrete policies to underpin the cement transition*. Climate Bonds Initiative (March 2023) https://www.climatebonds.net/files/reports/cbi-cement-policy.pdf

Capital and financing

Cement production is capital-intensive, and new projects such as upgrades and decarbonization methods require major investments. This means cement companies must make a compelling case to pay for major projects using retained earnings or from cashflow. This is where financing options come into play, of which there are many available. Given the sector's reliance on these external funding sources, funding can also act as an important lever in incentivizing (or penalizing) cement companies' decarbonization efforts.

Funding sources

The primary financing options for cement companies include:

- **Debt financing:** Bank loans, bonds, or syndicated loans in the case of large multi-operator projects
- **Equity financing:** Issuing new shares or investment from private equity
- **Government or institutional funding:** Grants, subsidies, or soft loans

Other funding sources are also available, such as vendor financing in which the cement producer allows a buyer to pay for their purchase over months or years to reduce the upfront cost burden. Leasing is also a viable alternative option.

Sustainability-linked loans (SLLs)

Sustainability-linked Loans (SLLs) in particular are becoming an increasingly important funding source. Designed to incentivize and reward companies for achieving sustainability targets, they are an effective way for cement companies to access capital while demonstrating their commitment to sustainable practices. These loans are linked to specific Key Performance Indicators (KPIs).

The interest rate on SLLs can be structured in two ways:

- **Coupon ratchet:** The interest rate decreases when the company achieves the agreed-upon sustainability targets
- **Margin adjustment:** The interest rate is adjusted (usually reduced) based on the company's performance against the sustainability targets

To ensure transparency and credibility, an independent third-party verifier is often engaged to assess and confirm the company's progress toward meeting the sustainability targets.

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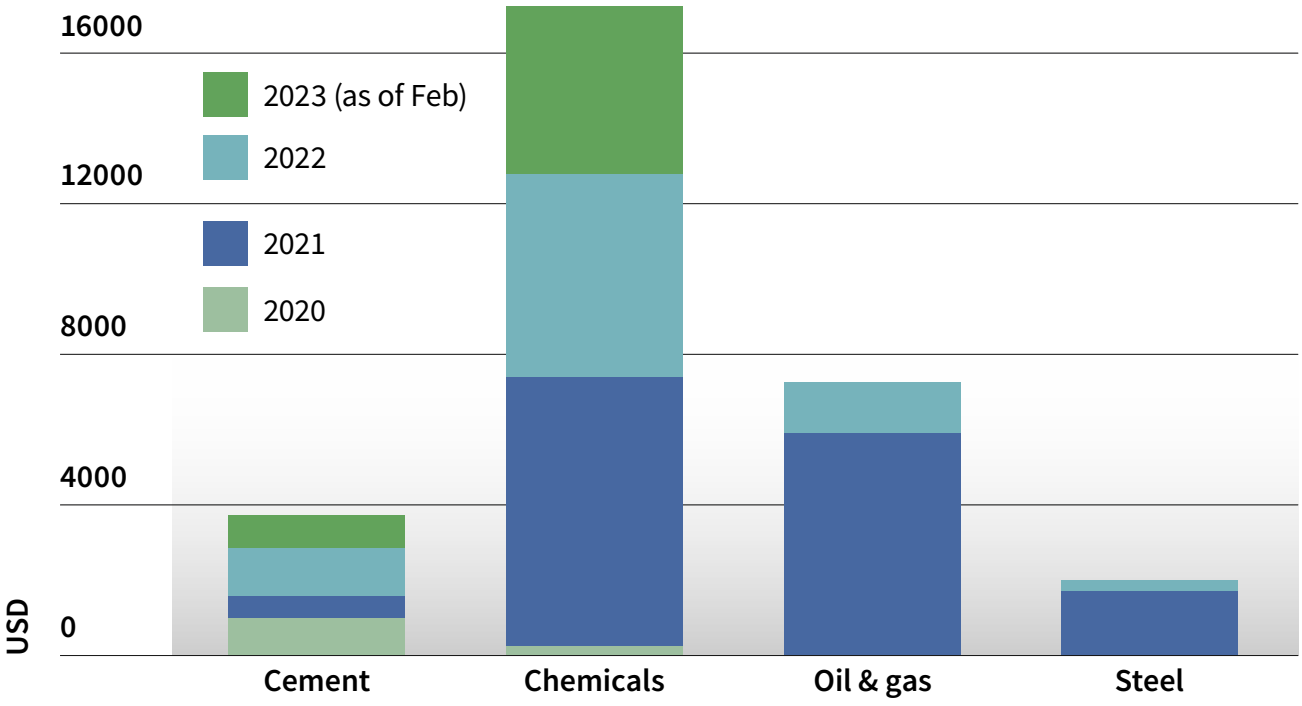
Between 2020 – 2023, approximately $3.7bn worth of SLLs have been issued in the cement sector, representing less than 2% of SLLs issues across all sectors.[58] This is below expectations, given the relative size and environmental importance of the cement sector, thus there is anticipation that more SLLs will be granted in subsequent years.

58 Passaro, Fabio. *Concrete policies to underpin the cement transition.* Climate Bonds Initiative (March 2023) https://www.climatebonds.net/files/reports/cbi-cement-policy.pdf

SLBs issuances by selected sectors 2020–2023



SOURCE: report from Climate Bond Initiative

Green bonds

Green bonds also have a place in the funding mix for cement companies. The core distinction between SLLs and Green Bonds centres on the allocation requirements. Green bonds are designated to finance specific environmental or climate-related projects, such as energy ventures, with the funds being strictly allocated to these predefined categories. A project's financing by a green bond is directly tied to the borrower's overall performance. SLLs, on the other hand, are linked to the borrower's achievement of specific performance objectives.

This delineation illustrates the adaptability of SLLs to various corporate contexts and sectors, making them an attractive financial tool for companies aiming to enhance their sustainability profile without a defined green project, whereas Green Bonds are more suitable for entities with clear environmentally beneficial projects to finance.

Role of governments

The role of governments in funding decarbonization is also gaining prominence. Governments can provide incentives such as tax breaks, grants, or low-interest loans for companies that invest in green technologies or practices.

The US in particular has taken a bold position through President Biden's Inflation Reduction Act (IRA), that is setting aside an unprecedented $690 billion to stimulate domestic efforts to achieve net zero. Although the main beneficiaries are energy producers, with huge investment going into the development of wind, solar and other alternative generation methods, the Department of Energy recently announced ~$6 billion in grants from the IRA to fund the decarbonisation of the most energy-intensive manufacturing sectors such as steel, cement, and chemicals.

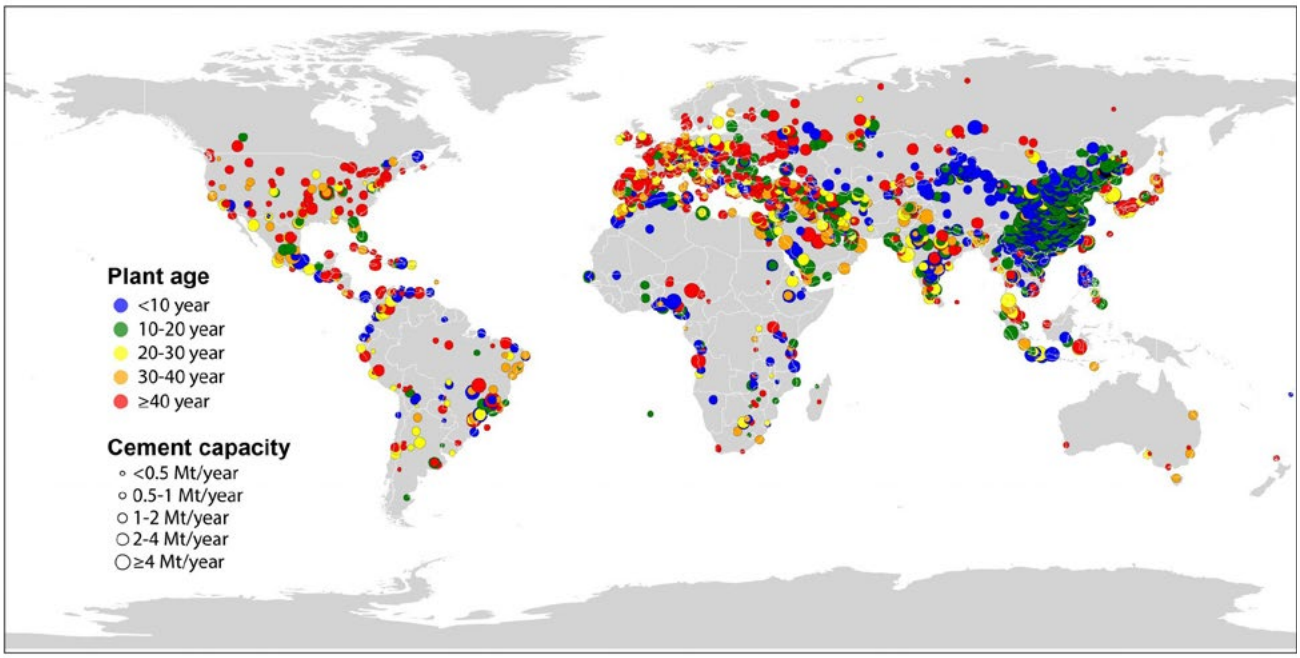
The European Union is progressing its own equivalent programme, the Net Zero Industry Act (NZIA) to identify decarbonization initiatives and projects and provide them with financial support to achieve their net zero goals. In April 2021, the UK government announced their Industrial Decarbonization Strategy to finance and support roadmaps for heavy industry to achieve reduced carbon emissions.

Although public spending on sustainable infrastructure is rising rapidly, it may not yet match the scale historically seen in traditional infrastructure such as roads and railways. However, the growth in green investment demonstrates a paradigm shift, reflecting a global recognition of the importance of sustainable development needed to mitigate the impacts of climate change.

Cement production is a global industry, there are cement plants in nearly every country. However, cement capacity has grown only in a handful of nations. As the map illustrates, China dominates in cement production capacity with an estimated 1.64 billion metric tons in 2022.[59] India and the United States, as well as regions such as the Middle East, have also seen significant growth to meet domestic demand. These accelerated boosts in mega producers means global decarbonization efforts will need to focus heavily on these countries with the highest carbon emissions.

In contrast to these regions with higher investments in cement, European manufacturers are driving capital into decarbonization initiatives rather than building new cement plants. This divergence is largely due to stricter regulatory requirements imposed on existing manufacturers, and public funding programmes to support sustainability efforts. Thanks to these government grants and incentives, European companies have been able to invest in decarbonization technologies and build long-term financial strategies to profit from these new regulations and programmes for greener growth.

Map of global cement infrastructure in 2019



SOURCE: GID-Cement Emission Database

59 *GID-Cement Emission Database.* Global Energy Infrastructure Emissions Database (2019). http://gidmodel.org.cn/?page_id=27

Conclusion

The cement industry, while indispensable to modern infrastructure, faces a formidable yet achievable challenge in addressing its substantial carbon footprint.

From the evolving global standards and regulations to the increasing demand for low-carbon cement products and the many decarbonization technologies available to producers, it is clear the landscape is undergoing a transformation. The commercial advantages of decarbonization, not only in reducing production costs but also in meeting the rising demand for environmentally friendly products will only increase over time.

Moreover, access to various sources of capital, including Sustainability-linked Loans (SLLs) and Green bonds, along with government incentives, presents a pathway for the industry to embrace and implement green technologies.

Levers of Change outlines a blueprint for the stakeholders of the complex cement ecosystem to navigate the regulatory and commercial factors steering decarbonization efforts in the industry.

Contact us

To discuss this paper, its findings and implications, please get in touch.

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